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IX

THE RELATION OF FORAMINIFERA TO THE ORIGIN OF CALIFORNIA PETROLEUM*

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Diatomaceæ are generally regarded by geologists as being the source of most of the petroleum of California. In 1867, J. D. Whitney, in a paper read before the California Academy of Sciences, called attention to the organic origin of the oil of the Pacific coast. The following is quoted from his paper:

"In conclusion, it may be remarked that the marine infusorial rocks of the Pacific Coast, and especially of California, are of great extent and importance. They occur in the Coast Ranges, from Clear Lake to Los Angeles. They are of no little economical, as well as scientific interest; since, as I conceive, the existence of bituminous materials in this state, in all their forms, from the most liquid to the most dense, is due to the presence of infusoria—the proofs of which statement I will, at some future time, endeavor to set before the Academy."[1]

Diatomaceæ at that time were classed with the Infusoria, their distinction not then being clear, but it is evident from the context of the article that Whitney referred to the Diatomaceæ as being the source of the petroleum. Whitney's paper is

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* Read before the Meeting of the Pacific Section of the American Association of Petroleum Geologists, Nov. 19, 1925, San Francisco, Calif.

[1] Whitney, J. D.—On the Fresh Water Infusorial Deposits of the Pacific Coast, and their connection with the Volcanic Rocks," Proceedings of the California Academy of Sciences, Vol. 1, 1854-1868, page 324.

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especially interesting as being perhaps the first published account of the organic origin of the oil of California.

The diatom-theory is now accepted by many geologists; several writers on California geology have, however, indicated their belief that Foraminifera have contributed to the origin of the oil. Many of the Cretaceous and Tertiary strata of California are rich in fossil Foraminifera, and their close connection in some cases with diatomaceous strata, and their proximity to producing oil fields have led geologists to the above natural conclusion.

Recent study and experiments conducted upon Foraminifera tend to show that they have contributed less to the origin of oil than has been believed.

Arnold & Anderson, discussing the origin of the petroleum of California, stated the following in their bulletin on the Coalinga District:

"The oils of the Coalinga district are believed to have been derived from two different sources, namely, the organic shales forming the uppermost member of the Chico (Upper Cretaceous) and those described as the upper portion of the Tejon (Eocene). It it believed that the oil originated from the organic matter, both vegetable and animal, once contained in these beds. The shales are composed in large part of the tests of foraminifera and diatoms, and a smaller number of other organisms, in such abundance as fully to warrant the assumption that the animal and vegetable material that must have been contained in them when deposited was adequate for furnishing a quantity of hydrocarbons and other compounds more than equivalent to the quantity of petroleum found in this field."[2]

Anderson & Pack, referring to the origin of oil in the foothill region north of Coalinga, indicated clearly their belief that Foraminifera contributed to the origin of the oil, although they considered the Diatomaceæ of most importance. Quoting from their writing:

"The oil-bearing zones of this region are the two diatomaceous and foraminiferal shale formations—the Moreno (Upper Cretaceous) and the Kreyenhagen (Oligocene?) and the sandy beds lying immediately above them. This fact points significantly to the two formations as the sources of the oil, and the writers firmly believe that the petroleum was derived

[2] Arnold, Ralph, and Anderson, Robert. Geology and Oil Resources of the Coalinga District, California; U. S. Geological Survey Bulletin 398, page 188, 1910.

from the organic matter once contained in the myriad shells of minute organisms of which these formations are largely composed."[3]

It is further stated:

"It cannot be said whether both the diatoms and the foraminifera or only one of these types of organisms furnished the organic matter from which the oil was produced, or which was the more important, but it seems probable that both contributed, with the possible addition of ingredients from still other organisms. Owing to the fact that the organic substance of plants is less readily decomposed than animal matter and would therefore be more certain to persist within the deposit until well buried and sealed, the diatoms are believed to have been the greatest contributors."[4]

Pack writes of the origin of the oil of the Sunset-Midway Field as follows:

"The chief reservoirs of petroleum in the Sunset-Midway District are the feebly consolidated sandy beds of the McKittrick group, but the petroleum is believed to have originated not in these beds, but in the fine-grained beds of organic origin that make up so large a part of the Maricopa shale and of the upper portion of the Vaqueros formation in certain parts of the region. These fine-grained beds are chiefly the so-called diatomaceous shales, which are composed in large part of the remains of minute plants and animals—diatoms and foraminifera—and it is from the decomposition and alteration of these organisms that the petroleum now found in the Sunset-Midway field results. In parts of the region the organic material contained originally in the fine-grained beds appears to be not so much the remains of diatoms as of larger terrestrial vegetation, and it is probable that part of the petroleum has been formed by the alteration of this coarser vegetal material. But in any case it seems clear that the ultimate source of the petroleum is the organic material originally contained in these beds."[5]

Vander Leck writes:

"The diatoms and foraminifera lived at the surface of warm inland seas, such as were present in what is now the great valley and coast regions of California, during the various geological ages from the Cretaceous to the present. These organisms dying, dropped to the bottom of the sea and together with other plant and animal matter formed an ooze or organic mud. Then, due to low temperature and absence of oxygen

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[3] Anderson, Robert and Pack, Robert W. Geology and Oil Resources of the West Border of the San Joaquin Valley North of Coalinga, California; U. S. Geological Survey, Bulletin 603, page 194, 1915.

[4] Op. cit. p. 199.

[5] Pack, R. W., The Sunset-Midway Oil Field of California, U. S. Geological Survey Professional Paper 116, page 70, 1920.

in quantities, a very slow decomposition, or putrification of the organic parts took place. It is, however, believed that no great quantity of liquid hydrocarbons were formed at this stage. These are believed to have formed when, due to earth movements, the mud or ooze was uplifted above the surface of the sea and by reason of the heat and pressure due to these movements and possibly aided by the action of saline waters, distillation of the shale took place, which resulted in the formation of petroleum."[6]

The above statements imply clearly the belief that Foraminifera were of considerable importance in contributing to the origin of the oil of California. This belief is based upon the following assumptions:

1. That Foraminifera were present in the Cretaceous and Tertiary seas in large numbers;
2. That the conditions of sedimentation were such as to bury a large proportion of the animal tissue along with the tests of the Foraminifera; and
3. That this animal tissue was wholly or in part converted into petroleum by the agency of pressure, heat and chemical or bacterial action.

Concerning the first and third of these assumptions, little need be said. Foraminifera were doubtless present in large numbers in the Cretaceous and Tertiary seas, as shown by the numerous fossil occurrences. Furthermore, it is reasonable to believe that a part at least of the animal tissue of Foraminifera may have been converted into petroleum by suitable reactions. That a large amount of animal tissue was actually buried in the strata, is, however, open to question. The following evidence is presented for the reason that it throws some light upon this problem.

Joseph A. Cushman, an American authority on Foraminifera, writes of their life history as follows:

"When the animal (Microspheric form) attains its adult stage, there is a great increase in the number of pseudopodia, and the entire protoplasm either leaves the test and accumulates about the exterior or is drawn into the outer chambers. Finally, each nucleus gathers a mass of protoplasm

[6]Vander Leck, Lawrence. Petroleum Resources of California; California State Mining Bureau, Bull. 89, page 13, 1921.

about itself and secretes the proloculum of a new test. The newly formed proloculum is of the larger type, and is the first chamber of the megalospheric form, instead of being of the same size as that of the microspheric parent from which it was derived. The megalospheric form differs from the microspheric in having a single nucleus. This does not divide, but moves along as new chambers are added, keeping in about the middle number numerically. Nucleoli appear in increasing numbers as the growth continues, and finally the whole nucleus breaks down and a great number of minute nuclei appear. These draw about themselves portions of the protoplasmic mass, and then divide by mitotic division. Finally, the mass leaves the test in the form of zoospores. These are then supposed to conjugate and to give rise to the small proloculum of the microspheric form, thus completing the life cycle, although the actual process of conjugation has not definitely been observed in this group. The empty tests left behind must form a large proportion of the dredged Foraminifera."[7]

Recently Cushman conducted some experiments in the Tortugas region of the Gulf of Mexico with living Foraminifera. One observation is significant in this connection:

"One important observation was that in the case of *Iridia diaphana* taken from *Posidonia* leaves and placed in petri dishes over night. In the morning some of these were found to have left their test empty and were moving about as naked masses of protoplasm with a free and comparatively rapid movement. That the animal may leave the test and pass some time without one is very significant from the standpoint of the method of growth. Growth of the test in those species which have a single chamber has often been a subject of speculation. If the test can be abandoned at will and another secreted or made by collecting more material in the case of those which have agglutinated tests, this difficulty is solved, and we may also understand how various sedentary species can collect various materials which are not common, for their tests."[8]

It appears from the above discussion of the life history of the Foraminifera that a very large portion of the tests preserved in the strata as fossils were empty of animal tissue at the time of burial. It is no doubt true that tidal action, ocean currents, decrease in the salinity of the waters, or other factors, impose upon Foraminifera conditions at times unfavorable for their existence, and that many may thus be killed and their tissues within their tests entombed. Some oil may have

[7] Cushman, Jos. A., Monograph of the Foraminifera of the North Pacific Ocean. U. S. National Museum, Bull. 71, page 7, 1910.

[8] Cushman, Jos. A., Shallow Water Foraminifera of the Tortugas Region, Carnegie Inst. of Washington, Vol. 17, page 8, 1922.

formed under these conditions. However, to account for the widespread destruction of foraminiferal life, and the accumulation and entombment of the animal tissue, such as would be necessary for the formation of oil in quantity, we must postulate unusual and extraordinary conditions of sedimentation recurring at intervals during and since Cretaceous time. Such conditions would lead to a sufficient accumulation of calcareous foraminiferal tests as to form considerable thicknesses of limestone, which are unknown in the Cretaceous and Tertiary formations of California. The fact that we do have several thousand feet of diatomaceous strata is considered strong support of the diatom theory. It appears probable from the above that Foraminifera have been of less importance than diatoms with respect to the origin of the petroleum of California.